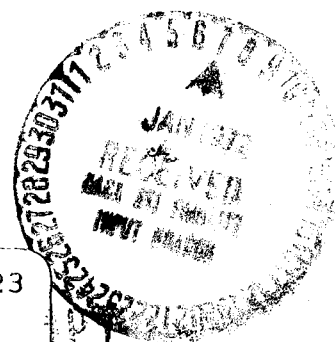
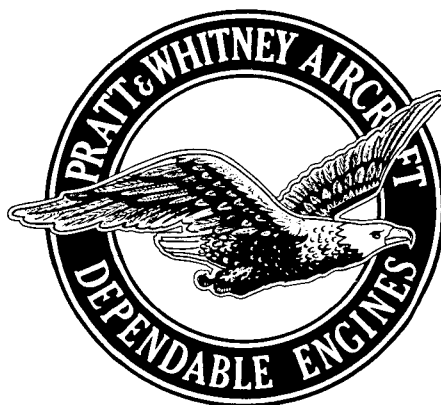


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Prepared for  
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2 July 1970

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DIVISION OF UNITED AIRCRAFT CORPORATION

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## SECTION I

### DESCRIPTION

#### POWERPLANT DESCRIPTION

The Pratt & Whitney Aircraft Fuel Cell Electrical Power Supply, PC8B-4 shown in Figure I, is an electrical powerplant designed to convert the chemical reaction of hydrogen and oxygen into electrical energy. The Fuel Cell Electrical Power Supply, PC8B-4, utilizes catalyzed electrodes with a potassium hydroxide electrolyte. Since many of the components have been developed and used in the Apollo Program, their performance characteristics are well documented. The PC8B-4 Fuel Cell Powerplant Flow Schematic is shown in Figure II.

Operating over a nominal power section temperature of 190° to 250°F, the powerplant provides direct current electrical power. Hydrogen and oxygen combine in the fuel cell to produce electrical power, water, and heat. Water is removed by recirculating hydrogen through the cells, and excess heat is removed by circulating coolant between the cells. Coolant enters the cell stack through the primary bypass valve. This valve modulates the coolant flow returning to the stack (or passing through the heat exchanger) to maintain stack coolant inlet temperature within pre-determined limits. A coupled reactant regulator maintains equal pressures between the reactants at the electrodes and limits the maximum reactant supply pressures to the fuel cell stack. The powerplant is capable of being started using no external power.

The hydrogen and steam circulate from the power section to a condenser which is also cooled by the circulating coolant. This mixture enters a centrifugal separator where the water is removed and transported from the powerplant. A water discharge valve assures that no hydrogen enters the water manifold.

#### TEST STAND CONTROL UNIT DESCRIPTION

The test stand control unit has three functions:

1. Sequence events during heat-up to insure a satisfactory start.
2. Provide switches to start, stop, and purge the powerplant.
3. Permit external power to be applied to the inverter and to the reactant purge valves in order to purge the power section of inerts prior to startup if the powerplant had previously been inerted. This same system may be used to fill the powerplant with inerts in the event of a shutdown initiated by the NASA automatic powerplant monitoring system.

In addition, the control unit has lights for monitoring purposes that indicate 400 cycle inverter output for each of 3 phases, and power to the purge valves. A light is also provided that signals "start complete" and indicates that the powerplant is ready for the application of an external load.

The control unit is mounted in a standard 19 inch electronics console rack which is compatible with other NASA test facility equipment. The rack also contains an inverter, manufactured by P&WA, which converts fuel cell power to 3 phase, 400 Hz, 120 volt current to operate the hydrogen and coolant pumps. Figure III, is a block diagram and Figure IV is an electrical schematic of the control unit. Figure V is a schematic of the inverter. Figure VI is a powerplant electrical schematic. Figure VII is a powerplant/test stand control unit electrical schematic.

#### A. Startup

To illustrate the operation of the test stand control unit, a chronological sequence of events for a normal start is given below. The only action required by an operator is to activate the two startup switches.

1. "Run-Stop" switch S-2 is place in "Run" position.
2. "Start" switch S-4 is momentarily closed.
3. This allows current to pass through K-1B and K-6A (both normally closed) which energizes K-3, closing K-3A (Figure III).
4. Once K-3A closes, K-3 is energized through D-8, allowing S-4 to remain open. The inclusion of the "start" switch in the circuitry provides manual activation of a reset circuit and prevents automatic reset resulting from the automatic shutdown requirement.
5. Closing K-3A also energizes K-2 which closes K-2A, opens K-2B, and closes K-2C. These three relays respectively provide power to the in-line heater; lock out external power; and provide power to the inverter.
6. Closing K-3A energizes K-7 (K-4B is normally closed) which provides power to the start-up heater through K-7A. Power is also provided to the start-up heater thermostat.
7. When the powerplant reaches operating temperature, the startup heater thermostat closes. This provides power to K-4 and PL-1 (the start-complete light).
8. K-4 closes K-4A which bypasses the startup heater thermostat. Power to K-4 is then fed directly. This allows K-4A to remain closed, and the start-complete light to remain on even though the thermostat will open at low temperatures.
9. K-4 also opens K-4B which denenergizes K-7, opening K-7A which turns the startup heater off.
10. When K-4A closes and the "start-complete" light, PL-1, comes on, S-5, the main feed contactor switch, may be closed, energizing K-5 and closing K-5A. This provides a signal to close a main feed contactor provided by the test facility.
11. When the main feed contactor is closed, an external load can be applied to the powerplant.

## B. Shutdown

In order to shutdown the powerplant manually the only action required of an operator is to turn the "run-stop" switch to "stop". Opening S-2, the "run-stop" switch, at any time will shutdown the powerplant. The sequence of events initiated by opening S-2, the "run-stop" switch, is as follows:

1. Power is interrupted to K-3 and K-2 which opens K-3A and K-2A, closes K-2B, and opens K-2C. This shuts off the inline heater; allows external power to be used if elected by closing S-1, and locks out fuel cell power to the inverter.
2. If S-2, the "run-stop" switch, is opened during heatup (startup heater on), power is interrupted through K-4B which shuts off the startup heater.
3. If the start has been completed, opening S-2 de-energizes K-4 which opens K-4A.
4. Opening K-4A de-energizes K-5 and opens K-5A which opens the main feed contactor.

## C. Normal Operation

The operating fuel cell controls work as follows.

1. When the powerplant is running, closing the "Manual Purge Fuel Cell Power" switch, S-3, provides power through D-11 to both purge valves. Power is also provided to PL-2, the "purge power on" light.
2. When the powerplant is not running, the purge valves are opened and the inverter is powered, by closing S-1, the "Manual Purge External Power" switch. Note that a 28 volt power supply must be provided for this operation.
3. By closing S-1, K-1 is energized, which closes K-1A. This provides external power to the inverter which operates the pumps.
4. Closing S-1 also provides external power to the purge valves and PL-2, through D-10. Power to other relays is blocked by D-11.

## D. Automatic Shutdown

Provisions have been made in the NASA facility to initiate an automatic shutdown under certain conditions selected by NASA. To initiate the shutdown, a signal to the test stand control unit is provided from the facility. An automatic shutdown is initiated by an external 28 volt signal to K-6.

1. Energizing K-6 opens K-6A, which de-energizes K-3 and opens K-3A. Opening K-3A provides the same functions as opening S-2, the "run-stop" switch.

2. When K-3A is open, K-2 de-energizes. This opens K-2A which interrupts power to the inline heater, closes K-2B which permits the use of external power for the pumps and purge valves, and opens K-2C which locks out fuel cell power to the inverter and pumps.
3. When K-3A is open, the main feed contactor is opened by interrupting power through K-5A. The startup heater, if on, is deactivated by the interruption of power through K-4B.
4. The initial external signal to K-6 also closes K-6B. Closing K-6B performs the same function as closing S-1, the "Manual Purge External Power" switch. That is, external power is supplied to the purge valves through D-10 and to K-1 which closes K-1A. Closing K-1A provides external power to the inverter and pumps.

### SPECIFICATIONS SUMMARY

Tables I and II present the operating limits of the powerplant and the interface requirements respectively.

TABLE I

#### Powerplant Operating Characteristics

<u>Conditions</u>	<u>PC8B-4</u>
Normal Voltage Range	27 to 32.5 vdc
Normal Power Range	350 to 4500 watts
Powerplant Nominal Operating Temperature	190°F to 250°F
Powerplant Nominal Fuel Outlet Pressure	60 psia
Powerplant Nominal Oxidizer Outlet Pressure	60 psia
Powerplant Nominal Condenser Outlet Temperature	158°F to 168°F

TABLE II

#### System Supply Requirements to Powerplant Interface

<u>System</u>	<u>PC8B-4</u>
Coolant Radiator Return Temperature	0°F to 120°F
Water System Discharge Back Pressure	50 psia maximum
Operating Environmental Temperature	+35°F to 130°F
Operating Environmental Pressure	10-6 mm hg to 1 atms.



TABLE II (cont.)

<u>System</u>	<u>PC8B-4</u>
Fuel Pressure	150 psia minimum to 1500 psia maximum
Fuel Temperature	0° to 120°F
Oxidizer Pressure	150 psia minimum to 1500 maximum
Oxidizer Temperature	0° to 120°F
Purge Valve Back Pressure	10 <sup>-6</sup> mm hg to 1 atm.
External Heat Exchanger Pressure Drop	4 psi maximum at 400 pph flow

## SECTION II

### PERFORMANCE

Fuel cell powerplant PC8B-4, consisting of a multi-cell module and related sub-systems as described in Section I of this manual, was designed to meet specific operational requirements. The performance data contained in this section is for standard operating conditions.

#### PERFORMANCE

Characteristics of this power system can be ascertained by the performance curve, Figure VIII. This is a plot of stack voltage vs. gross current. Powerplant characteristics during automatic startup are shown in Figure XVI.

#### OXYGEN CONSUMPTION

Plotted against gross power to show the consumption over the power spectrum. Purge requirements are not included. See Figure IX.

#### HYDROGEN CONSUMPTION

Plotted against gross power to show the consumption over the power spectrum. Purge requirements are not included. See Figure X.

#### WATER PRODUCTION RATE

Plotted against gross power to show water generation rate under stabilized operating conditions. See Figure XI.

#### HEAT REJECTION

Total heat rejected plotted against gross power for stabilized operating conditions. See Figure XII.

#### PURGE REQUIREMENTS

During normal operation, both reactant systems must be purged every 800 ampere-hours. The purge is to be maintained for two minutes. It should be noted that the 800 ampere-hour period is valid only if the reactant gases meet the purity specification requirements listed in Section III of this manual.

SECTION III

## REACTANTS SUPPLY AND CONTROL

REACTANTS SUPPLY

The powerplant is designed to operate with reactant gases of at least the purity levels defined by NAS-9-10368 paragraph III of Exhibit "A" which specifies NAR Procurement Specification MC 464-0015F dated 23 June 1966. Carbon bearing contaminants such as carbon dioxide may react with the electrolyte to form carbonates, which can have a deleterious effect on performance. Inert diluents such as nitrogen, on the other hand, will interfere with the normal flow of reactants to the reaction zone, and cause a temporary decrease in performance that can be corrected by purging.

The reactant supply system design should minimize the possibility of trapping air in the reactant lines during reactant tank installation or when transferring between main and reserve supply.

REACTANTS CONTROL SYSTEM

Two major functions are performed by the reactants control system.

1. To supply the fuel (gaseous hydrogen) and the oxidizer (gaseous oxygen) to the fuel cells on demand at the proper pressure.
2. To circulate the gaseous hydrogen at the proper flow rate and temperature in order to remove the product water.

Oxygen System - The oxidizer flow system supplies the cells with oxygen on demand. Oxygen from the supply flows through the oxygen pressure regulator and into the oxygen inlet manifold where it is distributed to the cells. From the cells, oxygen can flow through the outlet manifold to a vent line, containing a solenoid vent valve, and out to atmosphere. The gas manifolds are an integral part of the cell stack. Oxygen at regulated pressure is also supplied to the gas side of the coolant accumulator.

Hydrogen System - The hydrogen system is designed so that the incoming make-up hydrogen supply gas passes through a regulator and combines with the hot hydrogen and water vapor mixture exiting from the power section.

The combined flow goes to the condenser, where the steam is cooled and the water separated from the fuel. A vane type hydrogen pump, driven by an electric motor, is mounted in the hydrogen recirculation system between the condenser and the power section to compensate for the loop pressure losses.

A vent line is connected to the hydrogen circulation system between the condenser and the hydrogen stack exit.

REACTANT PURGE PROVISIONS

Hydrogen and oxygen system purge lines must be provided. The vent sides of the pressure regulators also tie into the powerplant purge systems downstream of the purge valves but upstream of the powerplant interface. During powerplant operation the facility reactant purge lines must be open to atmospheric pressure or less to insure that the reactant regulator can vent if required.

## SECTION IV

### HEAT REMOVAL

#### HEAT INPUT

Once the powerplant is in automatic operation, it is self-sustaining and the system temperatures are automatically controlled.

#### HEAT REJECTION

Heat generation occurs at the reaction sites in both electrodes. Therefore, an external radiator is required.

Heat is removed from the cell by two means.

1. By radiation and conduction from the powerplant.
2. By circulating a coolant through cooling plates which are an integral part of each cell in the stack.

The coolant enters the cell stack, flows through the cell coolant manifold, and is distributed in parallel to the cooling plates in each cell. The dimpled cooling plates, which press against the electrodes, provide a heat path between the electrodes and the coolant. The coolant picks up heat uniformly over the electrode surface and leaves the cell stack at an elevated temperature. As the module gross current is increased, the coolant temperature rise through each cell is increased.

The coolant leaving the cell stack is pumped either to the power section inlet leg or to a heat exchanger leg. During startup and low power operation, the inlet control valve allows the coolant to bypass the heat exchanger and return directly to the power section. This arrangement retains heat in the system and, when starting, allows the stack to reach operating temperature in a minimum of time.

At higher power settings, heat must be removed from the system. This is accomplished by the control valve directing some of the coolant to the heat exchanger. The amount of coolant flowing through each leg is determined by the control valve. The control valve is activated by a temperature sensing element located in the power section inlet line.

An external heat exchanger must be provided to remove heat from the powerplant coolant. This heat exchanger in a spacecraft might be the radiator, but in a ground test stand, it must be part of the facility. This heat exchanger is located in the second leg. A temperature sensing element located in the condenser exit hydrogen line activates a control valve used to bypass this external heat exchanger. The coolant passes through the condenser, rejoins the coolant from the first leg, and then enters the power section.

SECTION V

## WATER REMOVAL

GENERAL

In addition to electrical power and heat, the electro-chemical reaction of hydrogen and oxygen produces water. The water, which is formed in the vicinity of the hydrogen electrode-electrolyte interface, is removed by a hydrogen circulation system. Hydrogen gas flows past the electrode, absorbing water vapor and transporting it to a condenser, where the water vapor is converted to liquid. The saturated hydrogen and condensed water are then carried to a centrifugal separator which removes the liquid. The water is then transported to the collection system through a pitot tube-valve combination which prevents hydrogen from entering the product water system. The hydrogen gas and residual water vapor, corresponding to the saturation partial pressure at the condenser exit, is circulated to the cell by an electrically-driven vane pump.

Since gas regulators maintain constant cell pressure and a constant speed pump maintains an essentially constant hydrogen flow rate, it follows that the amount of water removed from the cell is proportional to the difference between specific humidities at the exit and inlet of the cell stack. (The specific humidity is defined as the ratio of the mass of water vapor to the mass of hydrogen in the circulation stream). The specific humidity at the cell inlet is a function only of the condenser exit temperature.

The specific humidity at the cell exit can be equated to the partial pressure of the water vapor in equilibrium at the electrolyte interface, which is a function of electrolyte concentration. The electrolyte concentration in turn is a function of temperature which is a function of powerplant load.

SECTION VI

## INSTRUMENTATION

GENERAL

Only limited instrumentation is furnished with the powerplant.

OPERATIONAL INSTRUMENTATIONCell Voltage

Individual cell voltage can be monitored. Each cell is wired to a connector to facilitate this measurement.

Module Voltage

Total powerplant voltage can be measured across the main load leads.

Current

A shunt is provided for measurement of gross current. Two connector pins are provided at the P/P interface.

Reactant Regulated Pressure

Pressure taps are provided downstream of the oxygen and hydrogen regulators.

Temperatures

Identical thermistors are provided to measure coolant stack inlet, coolant stack outlet, hydrogen condenser exit temperature, and radiator return temperature. Thermistor leads terminate in an interface connector.

Figure XIII gives the characteristics of these thermistors.

Purge Indicators

Each purge valve contains a pressure switch which, when monitored, is a positive indication of purge flow. Two pins for monitoring each of these switches are provided at the powerplant interface.

SECTION VII

## OPERATION

GENERAL

A general operating procedure is given. No attempt is made to describe the operation of user supplied equipment.

REMOVAL FROM SHIPPING CONTAINER

Make a thorough visual inspection of the exterior of the powerplant for evidence of damage that might have occurred during transportation or handling.

GAS, LIQUID, AND ELECTRICAL REQUIREMENTS

Operation of the powerplant requires support equipment that will supply the gases and liquids regulated to the pressures and flows in accordance with the requirements listed below:

- a. Hydrogen meeting NAR Procurement Specification MC 464-0015F dated 23 June 1966 or better, to be supplied to the fuel inlet at a pressure between 150 and 1500 psia, at a minimum temperature limit of 0°F, and a maximum temperature limit of +120°F.
- b. Oxygen meeting NAR Procurement Specification MC 464-0015F dated 23 June 1966 or better, to be supplied to the oxidizer inlet at a pressure between 150 and 1500 psia, at a minimum temperature limit of 0°F, and a maximum temperature limit of +120°F.
- c. Coolant requirements are as follows:
  1. The coolant to be used in the powerplant is pure FC75, (Fluorocarbon liquid product of the 3M Company).
- d. Generated water collection system.

A water collection system must be provided capable of accepting product water at a maximum of 50 psia back pressure.

EQUIPMENT REQUIREMENTS

Additional support equipment includes the following listed items:

- a. One vacuum pump for evacuating the coolant system prior to fill. The pump shall be capable of evacuating the coolant system (approximately 100 cu. in.) below 1.0 in. Hg absolute pressure.

- b. A coolant fill system capable of filling the powerplant with coolant in accordance with the procedure given under Coolant Fill. (Figure XIV).

#### PREPARATION OF POWERPLANT PRIOR TO START

Make the following connections to the system after removing adapter protective caps:

a. Plumbing Connections - Powerplant Interface:

1. Fuel Supply - #4 AN Male
2. Fuel Vent - #4 AN Male
3. Oxidizer Supply - #4 AN Male
4. Oxidizer Vent - #4 AN Male
5. Water Outlet - #4 AN Male
6. Coolant Inlet - #6 AN Male
7. Coolant Outlet - #6 AN Male

Care must be taken to insure that the proper facilities connections are made at the powerplant interface. The powerplant interface fittings are clearly identified on the powerplant.

b. Electrical Connections:

1. Power Output
2. Startup Heater Current

c. Control Connections, Test Stand Control Unit, see Electrical Schematic Figure VII.

d. Instrumentation Connections:

1. Volts
2. Amps (Gross)
3. Coolant In Temperature
4. Coolant Out Temperature
5. Condenser Exit Temperature
6. Radiator Return Temperature

e. Figure XV is a table of electrical connectors.

#### SYSTEM COOLANT FILL PROCEDURE - See Figure XIV

- a. Pull the 8 amp inverter fuse (F3) from the test stand control unit. This will permit using external power to open the purge valves without running the pumps.
- b. Close valves "B" and "C".
- c. Fill the coolant reservoir.



- d. Using valve "C", bleed line between coolant reservoir and reservoir isolation valve "B". After bleeding, close valve "C".
- e. Open the powerplant reactant system-purge valves using external power - note Item "a" above.
- f. Insure that valves "D", "E", "F", and "G" are open.
- g. Evacuate the coolant system to at least 29 in. Hg as indicated on gage "2".
- h. Isolate the vacuum pump by closing valve "D".
- i. Decay check the system. Once inch Hg decay in 30 minutes is acceptable.
- j. Isolate the vacuum gage by closing valve "F".
- k. With valve "A" still closed, pressurize gauge "1" to 2 psig. If there is a significant head loss or head rise between the coolant reservoir and the powerplant, this must be taken into account. Care must be taken to see that the coolant pressure at the powerplant interface is 2 psig  $\pm$  1 psig. At no time must this pressure be exceeded.
- l. Open valve "A" to pressurize the coolant reservoir.
- m. Open valve "B" to fill the coolant system.
- n. Allow at least ten minutes for the system to stabilize after flow stops.
- o. Isolate the powerplant/radiator coolant system by closing valve "G".
- p. Disconnect the coolant fill system from the powerplant/radiator coolant system at fitting "Z".
- q. Close powerplant reactant purge valves.
- r. Pressurize the powerplant reactant systems with H<sub>2</sub> and O<sub>2</sub> to full regulated pressure (60 psia). Drain 350 cc of coolant through valve "G" and fitting "Z".
- s. Cap off fitting "Z".
- t. Remove external power supply.
- u. Replace inverter 8 amp fuse.

POWERPLANT STARTING

## a. Interface Conditions

Prior to start, conditions at the powerplant interface shall be as follows:

1. Place main feed contactor switch in "open" position.
2. Fuel and oxidizer supply pressure within listed limits.
3. Terminal voltage above 34.5 volts. It may be necessary to purge reactants until voltage meets this requirement particularly if the powerplant reactant systems had been purged with an inert gas for long term storage, shipment, or emergency shutdown.

## b. Heatup

1. Place "run-stop" switch in "run" position.
2. Momentarily actuate "start" switch.
3. Purge reactants for first two minutes of start.
4. When start-complete signal lights, place MFC switch in "closed" position and proceed with normal operation.

NORMAL OPERATION

- a. Load powerplant to desired operating level within specification limits.
- b. Sustained operation - during normal sustained operation, reactants consumption, water production, heat rejection, and power output are as defined in the performance section of this manual.
- c. Insure that the limits given in the specification summary of this manual are strictly adhered to.

SHUTDOWN

- a. Place "run-stop" switch to "stop". Even though this will automatically open the main feed contactor, it would be advisable to remove the external load and open the main feed contactor switch.
- b. Cool to ambient temperature.
- c. Note that instrumentation loads (if any) or any other electrical load across the powerplant must be removed at shutdown. Care must be taken to insure that a non-operating powerplant is never electrically loaded.

d. For shipping and long periods of storage, the reactant systems should be inerted as follows:

1. Close stand fuel and oxidizer supply valves.
2. Using external 30 volt power supply, open purge valves and depressurize reactant systems to ambient, pumps will also be running.
3. Introduce  $N_2$  into both reactant systems from a supply with pressure at least 250 psia. If the stand  $N_2$  systems are not integral with the stand reactants systems, a nitrogen supply can be temporarily plumbed upstream of the stand reactants supply valves. Purge nitrogen through the system for at least 10 minutes.
4. Close stand reactants supply valves.
5. Leave purge valves open (pumps will continue to run) until pressure in reactant compartments has been reduced to ambient.
6. Close purge valves.

NOTE: The emergency shutdown system at the NASA facility performs the shutdown and inerting procedure automatically.

## SECTION VIII

### SAFETY CONSIDERATIONS

#### OBJECTIVE

The objective of this section is to focus attention on the general subject of safety pertaining to the powerplant. The discussion herein will merely feature certain highlights and should not be construed as comprehensive coverage of the subject matter.

Specific health and safety recommendations will, as always, continue to be the responsibility of the user's cognizant personnel, utilizing commercially available information covering in detail all items pertaining to the materials involved.

#### OPERATIONAL SAFETY MARGIN

The PC8B-4 is designed to operate safely and dependably as a space power unit under the conditions described in this handbook.

Pratt & Whitney Aircraft has given careful attention to the possibilities of component malfunction which might occur during operation. The operational safety of a hydrogen-oxygen fuel cell powerplant was investigated early in the development program and continues to be an active design factor as the technology grows.

#### SAFETY PRECAUTIONS

In the case of the PC8B-4, the safety precautions concern primarily the handling of potassium hydroxide and the reactant gases as highlighted briefly in the following paragraphs.

##### a. Potassium Hydroxide (KOH)

Ordinarily, the only persons in contact with KOH are the Pratt & Whitney Aircraft technicians who fill each cell. However, the necessary precautions are included here for completeness. Thorough precautions should be taken to keep personnel from direct contact with this caustic electrolyte. It is suggested that a sterile buffer solution, composed of primary and secondary phosphates similar to those present in all human and other vertebrate tissue, be maintained in close proximity to any area where KOH is handled to facilitate immediate, thorough, eye or skin irrigation and caustic neutralization, should an accident occur. Such buffer solutions are commercially available.

## b. Hydrogen

Hydrogen gas, used as the PC8B-4 fuel, is normally colorless, odorless, tasteless, lighter than air, and practically insoluble in water. It is nontoxic.

This gas, without a source of ignition, is chemically inert with all common materials. Leaking hydrogen gas will dissipate rapidly into the atmosphere.

Physical properties of Hydrogen are:

Atomic Weight	1.0080
Molecular Weight	2.016
Density	0.0052 lb/ft <sup>3</sup> at 70°F and 1 atmosphere
Specific Volume	192 ft <sup>3</sup> /lb at 70°F and 1 atmosphere

## a. Oxygen

Oxygen, used as the PC8B-4 oxidizer, is an active element which, though it does not burn, is necessary to support combustion of other materials. It combines directly or indirectly with all the known elements except the rare gases. Oxygen is a gas which is normally colorless, odorless, tasteless, heavier than air, and slightly soluble in water.

Although gaseous oxygen presents no direct health hazard, it is necessary to assure absolute cleanliness of all material which may come in contact with it. Oil-contaminated clothing, gloves, gages, valves, etc., must not be used around oxygen; otherwise a flash fire and/or explosion could result.

Physical properties of Oxygen are:

Atomic Weight	16.00
Molecular Weight	32.000
Density	0.083 lb/ft <sup>3</sup> at 70°F and 1 atmosphere
Specific Volume	12.08 ft <sup>3</sup> /lb at 70°F and 1 atmosphere

REACTANT GAS LEAK DETECTION

When hydrogen is mixed in certain proportions with air, oxygen, and other oxidizers, a highly flammable mixture is formed. In air, the explosive limits for normal hydrogen are 4.1 to 74.2% by volume. Ignition of hydrogen-air mixtures takes place with low energy input. An invisible spark, for instance, could cause an explosion. On the other hand, auto-ignition temperature is 1085°F.

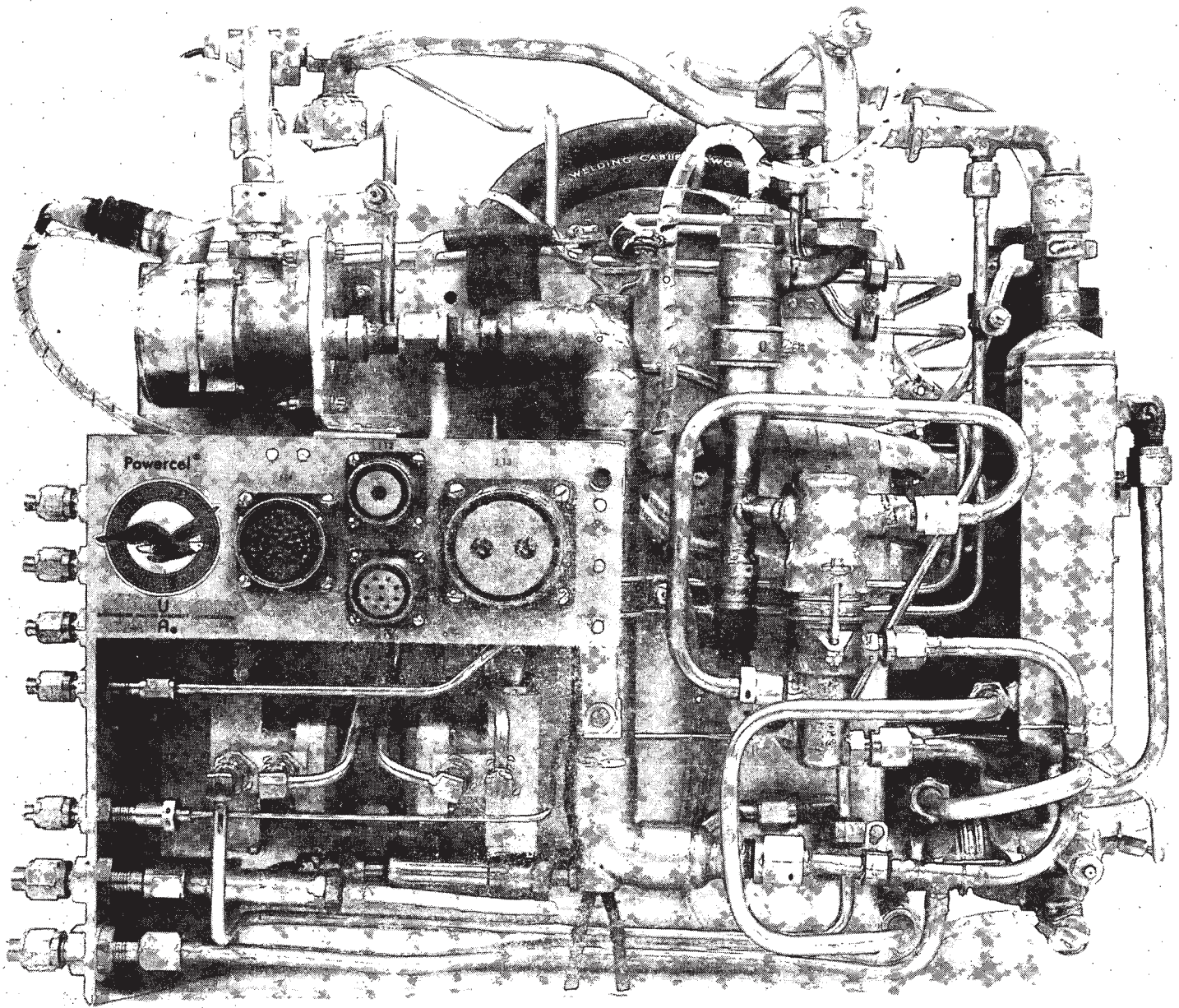
Furthermore, the explosive limits described above can be varied by adding another gas as a diluent. In general, inert gases tend to raise the lower explosive limit, whereas the presence of oxygen can increase the hazard by widening the explosive limit range.

Therefore, determination of the concentrations of both hydrogen and oxygen should be accomplished continuously in any closed building in which both gases are present. Instruments for hydrogen and oxygen detection and concentration measurement are commercially available. These are of various types, ranging from small portable detectors to fixed units which can sample many points continuously.

These concentration detection units can be either indicating or recording types, and installation can include automatic actuation of warning devices or other equipment. The manufacturer's instructions should be carefully followed when these detectors are used.

The potential danger of hydrogen is the highly flammable atmosphere created when it mixes in certain proportions with air, oxygen, or other oxidizers.

The basic safeguards for preventing a hydrogen explosion are the same as those applying to all flammable gases, namely: (1) preventing an explosive mixture buildup by allowing free escape of leaking gas out roof vents, (2) installing leak detection equipment, and (3) guarding against all potential sources of accidental ignition.



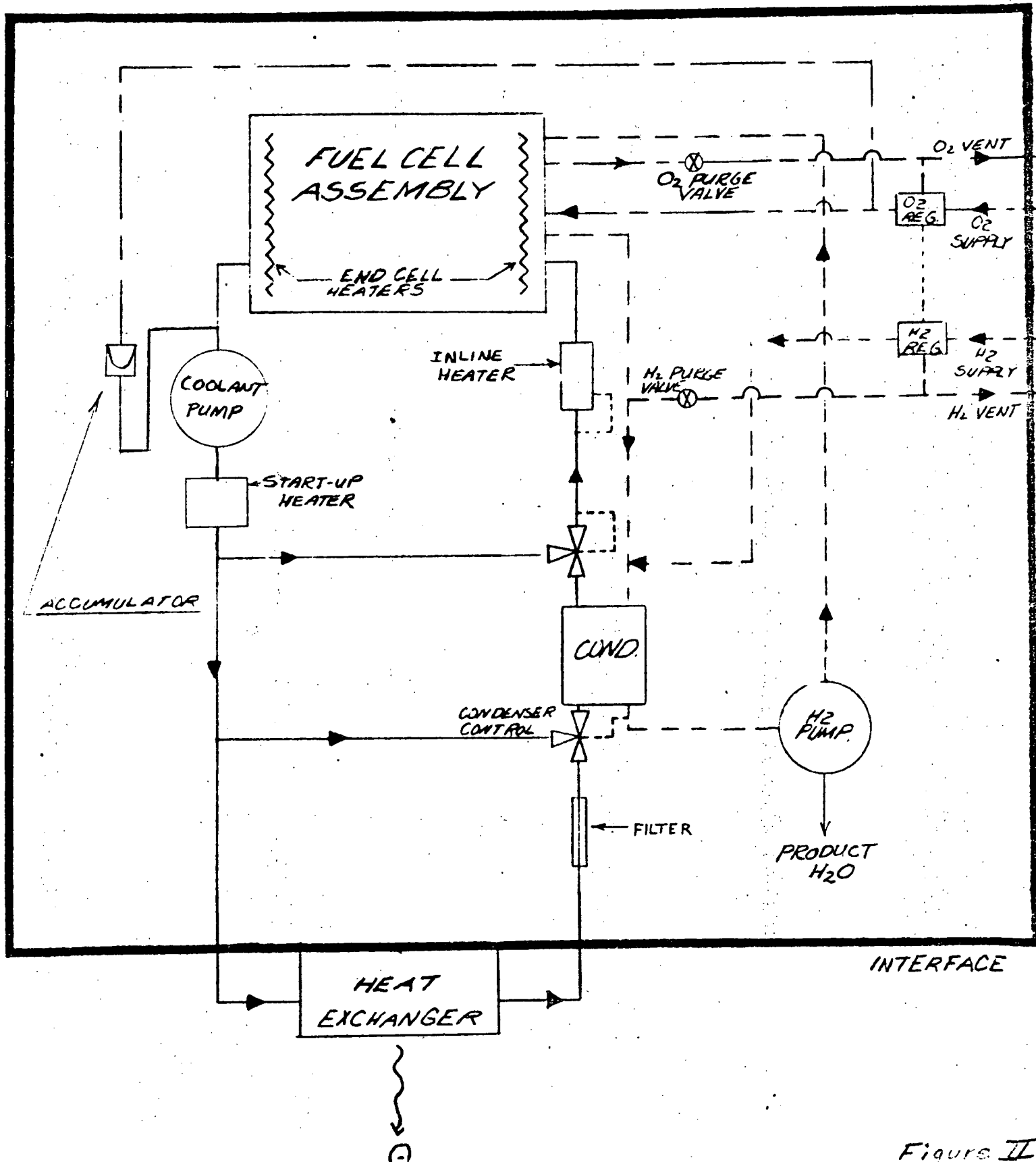
PC8B-4 NASA Powerplant X-562.

WCN-804

FIGURE 1

# PC8B-4 FLOW SCHEMATIC X-562

----- H<sub>2</sub>  
 ===== O<sub>2</sub>  
 ===== COOLANT  
 ===== INTERFACE





EXPERIMENTAL ENGINEERING SKETCH PWA F-33423 3 50

WORK TO DIMENSIONS GIVEN - DO NOT SCALE

UNLESS OTHERWISE SPECIFIED

- BREAK SHARP EDGES .003" DIA
- CORNERS TO HAVE FILLETS
- .005" .020 RAD

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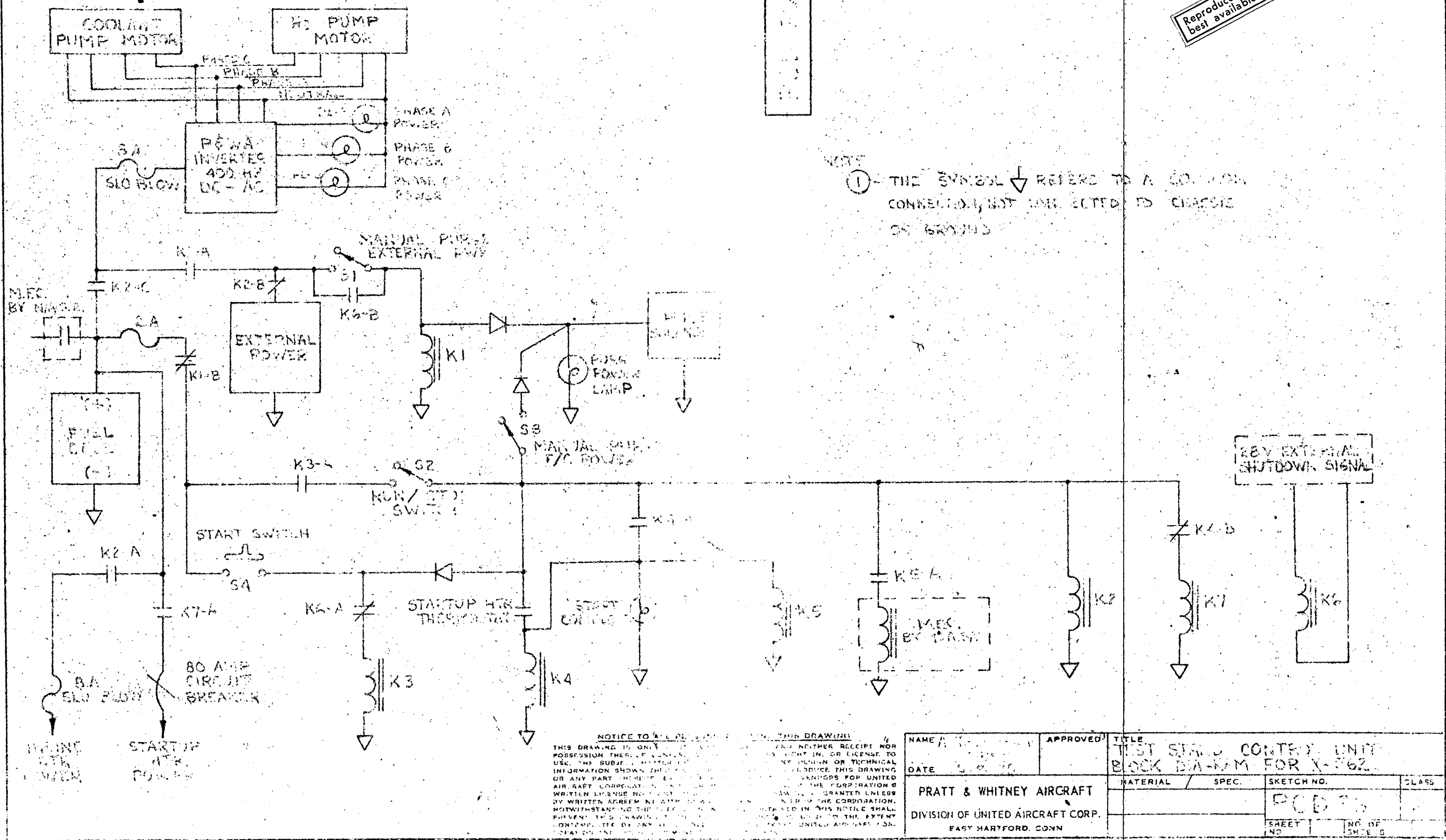
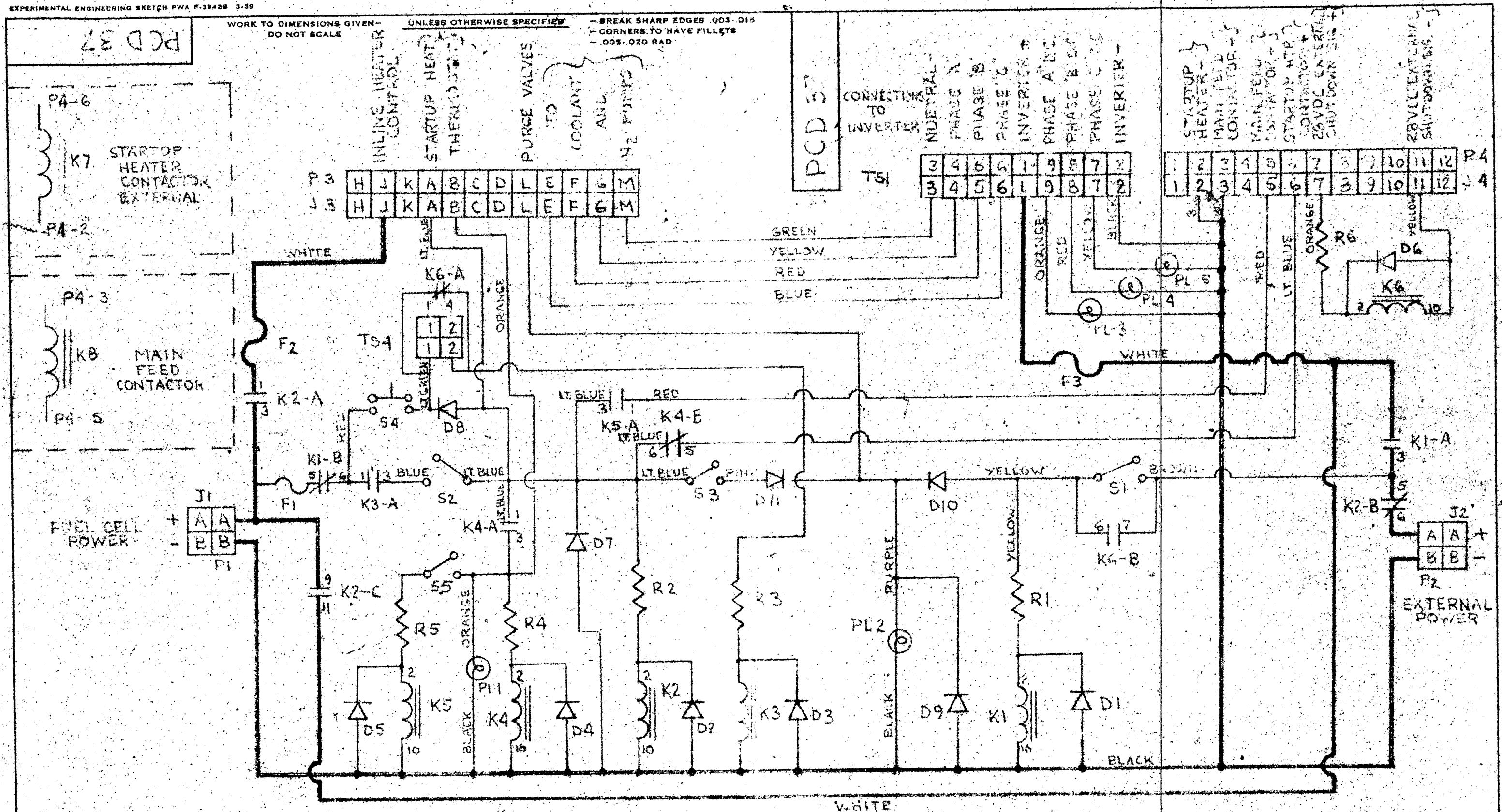


FIGURE III

EXPERIMENTAL ENGINEERING SKETCH PWA F.3942B 3-59

WORK TO DIMENSIONS GIVEN -  
DO NOT SCALE

UNLESS OTHERWISE SPECIFIED

- BREAK SHARP EDGES .003-.015  
- CORNERS TO HAVE FILLETS  
- .005-.020 RAD

## NOTES

- ① HEAVY LINES ARE #16 WIRE
- ② ALL OTHER WIRING #20

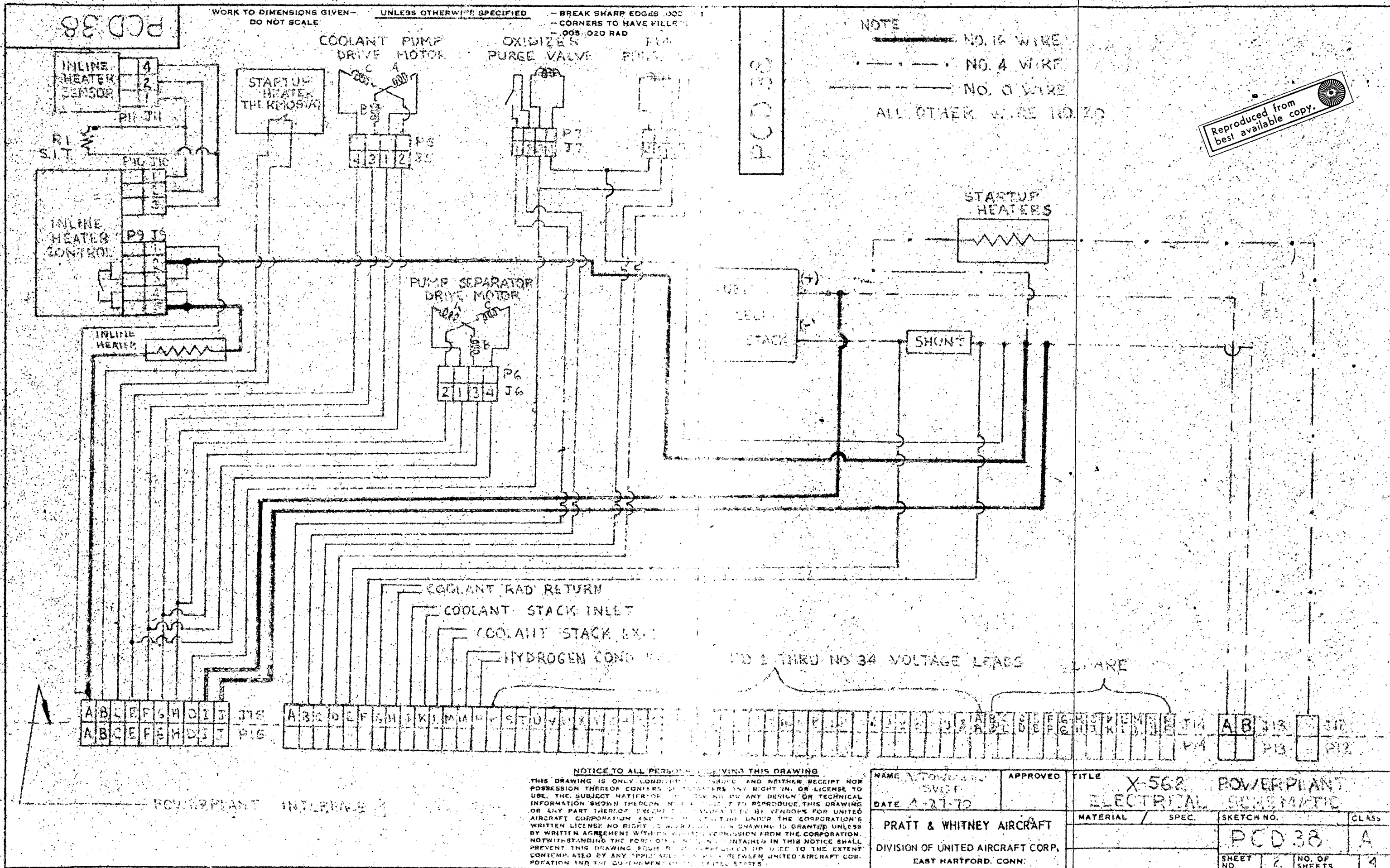
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NAME A. T. C. H. I.	APPROVED	TITLE X-562 TEST STAND CONTROL UNIT ELECTRICAL SCHEMATIC	
DATE 9 8 59		MATERIAL / SPEC.	CLASS
PRATT & WHITNEY AIRCRAFT DIVISION OF UNITED AIRCRAFT CORP. EAST HARTFORD, CONN.		SKETCH NO. 4 PCD 37	A
		SHEET NO. 1	NO. OF SHEETS 4

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EXPERIMENTAL ENGINEERING SKETCH PWA F-3342B 8-59



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FIGURE VII

PCD 59

WORK TO DIMENSIONS GIVEN—  
DO NOT SCALE

UNLESS OTHERWISE SPECIFIED

—BREAK SHARP EDGES .003  
—CORNERS TO HAVE FILLETS  
—.005, .020 RAD

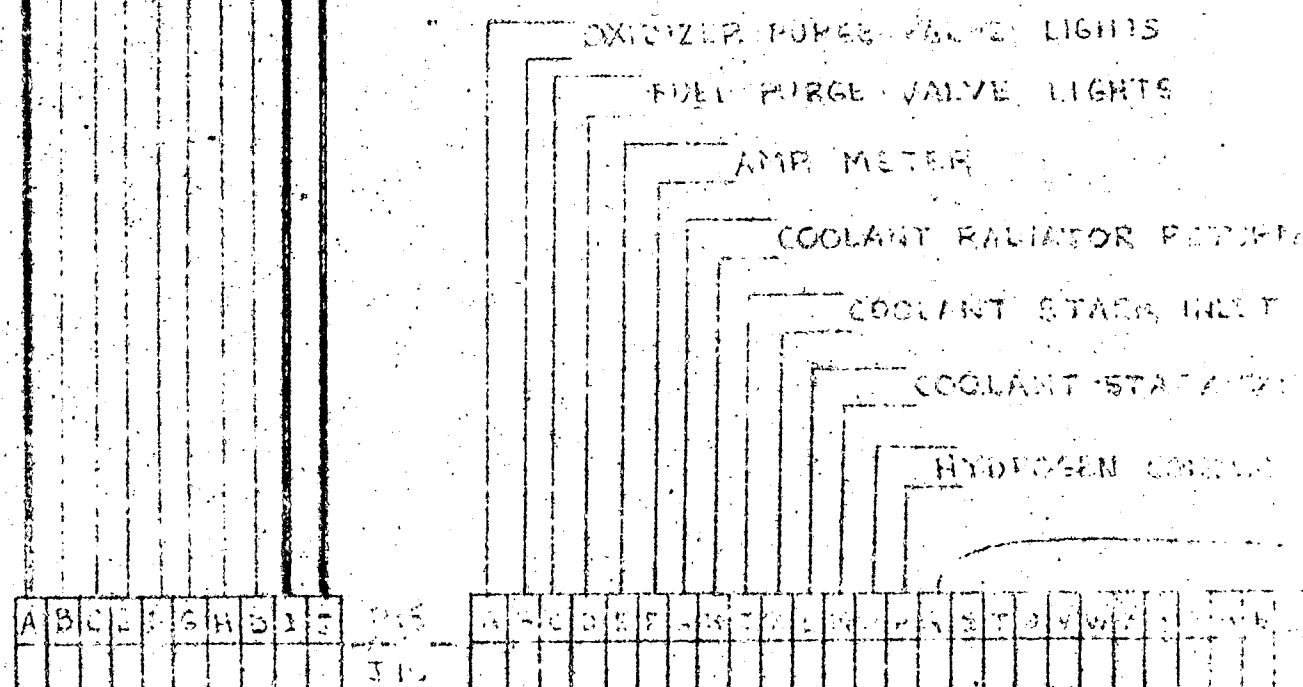
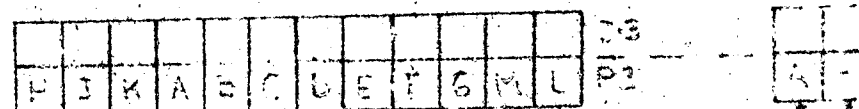
NOTE

NO. 16 WIRE

NO. 18 WIRE

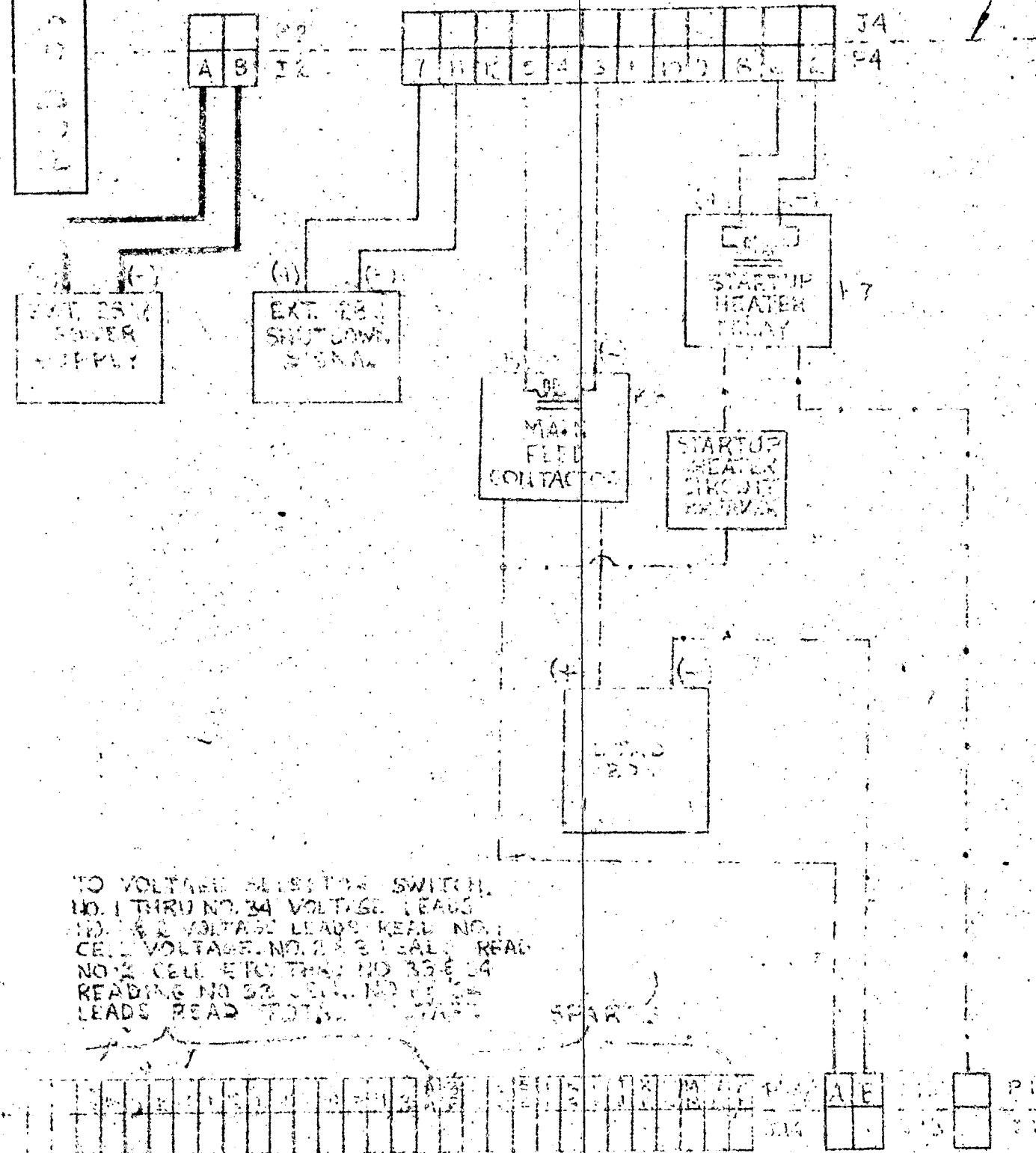
NO. 20 WIRE

ALL OTHERS WIRE NO. 20



POWER UNIT INTERFACE

TEST STAND CONTROL UNIT INTERFACE



TO VOLTAGE SELECTOR SWITCH.  
NO. 1 THRU NO. 34 VOLTAGE LEADS  
NO. 35 VOLTAGE LEADS READ NO.  
CELL VOLTAGE. NO. 36 & 37 LEADS READ  
NO. 2 CELL ETC. THRU NO. 33 & 34  
LEADS READ TOTAL VOLTAGE

SPARE

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NAME	APPROVED	TITLE	
		X-562 POWER/TEST STAND CONTROL UNIT SCHEMATIC	
DATE		MATERIAL	SPEC.
PRATT & WHITNEY AIRCRAFT		SHEET NO.	CLASS
DIVISION OF UNITED AIRCRAFT CORP.		PCD 59	A
EAST HARTFORD CONN		SHEET NO.	NO. SHEETS



# FC88-A, RESC2 PERFORMANCE CHARACTERISTICS

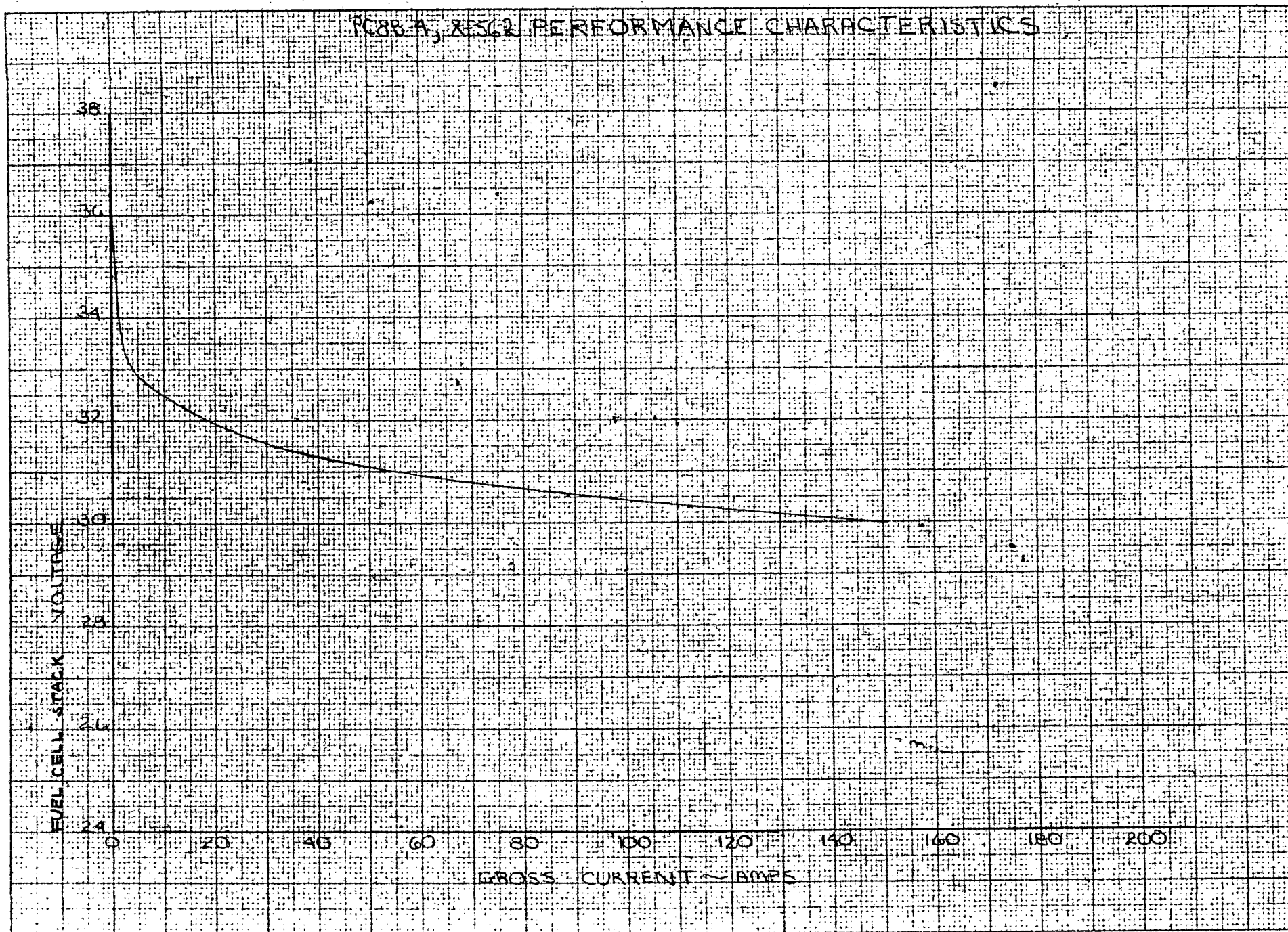


Figure VIII

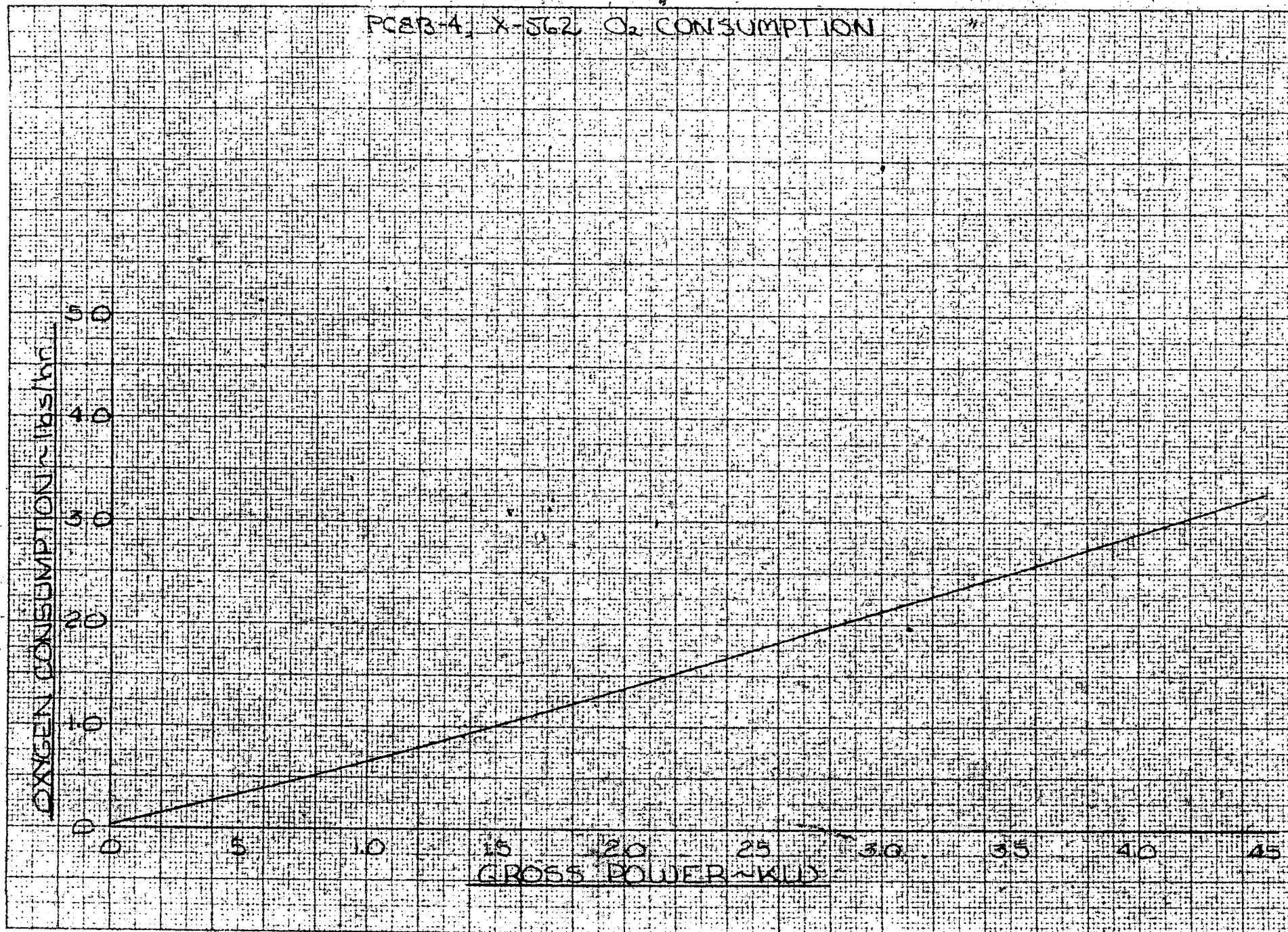


Figure IX

PCBB-A, X-562 H<sub>2</sub> CONSUMPTION

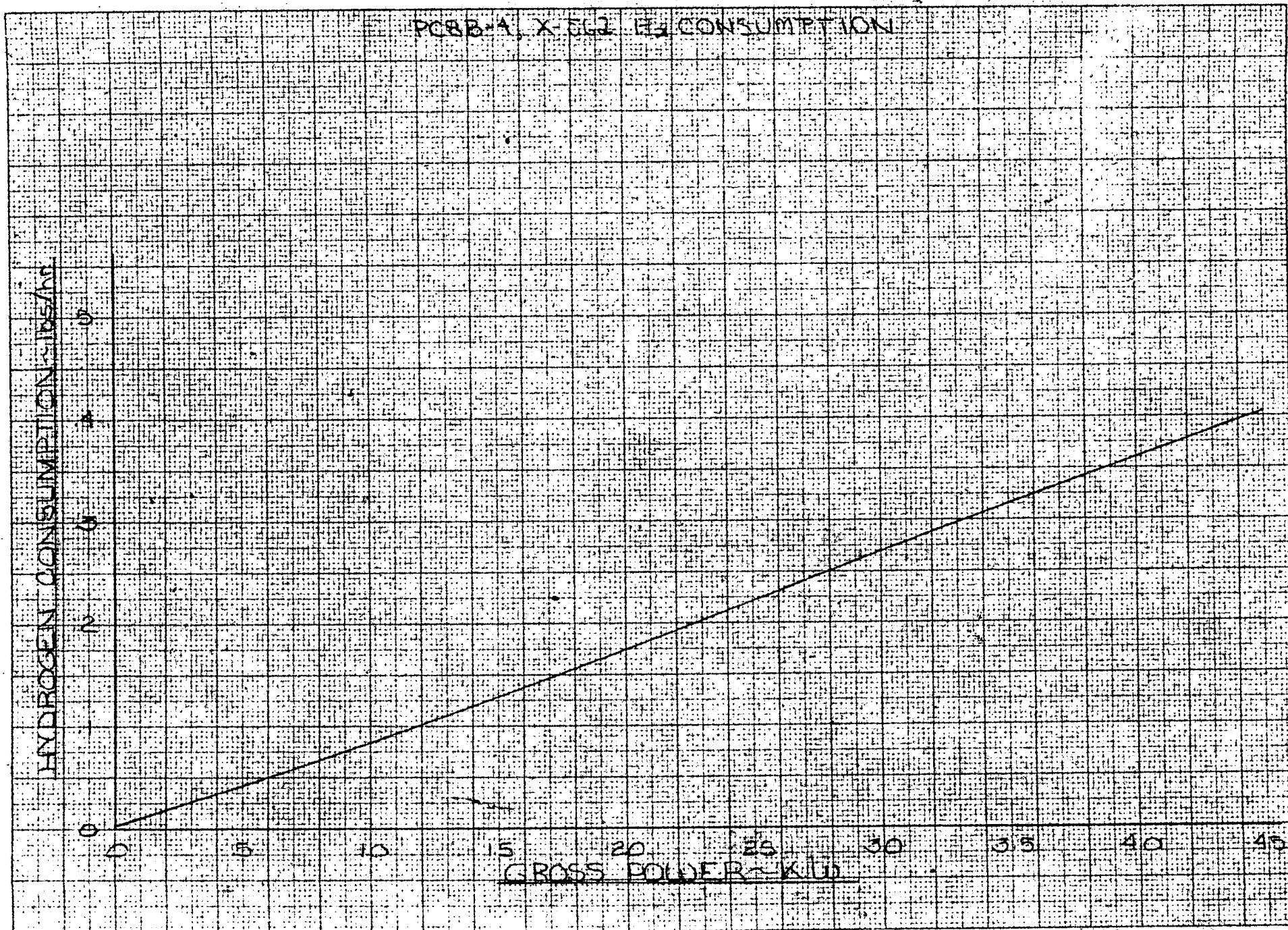


Figure X



PCBB-4, X-542 WATER GENERATION

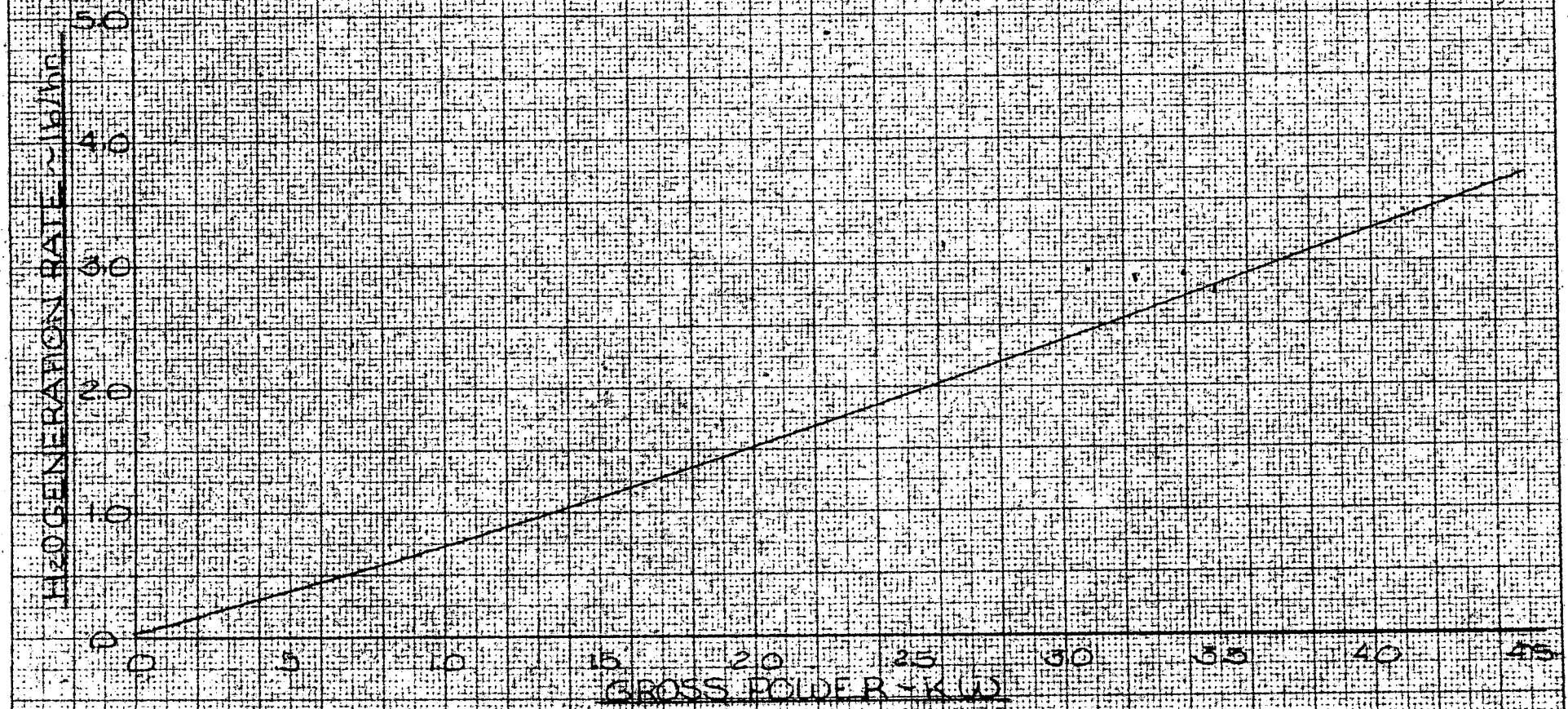


Figure XI

# POB-4, X-502 MAXIMUM HEAT REJECTION

2500 HR. PERFORMANCE  
ON HEAT LOSS

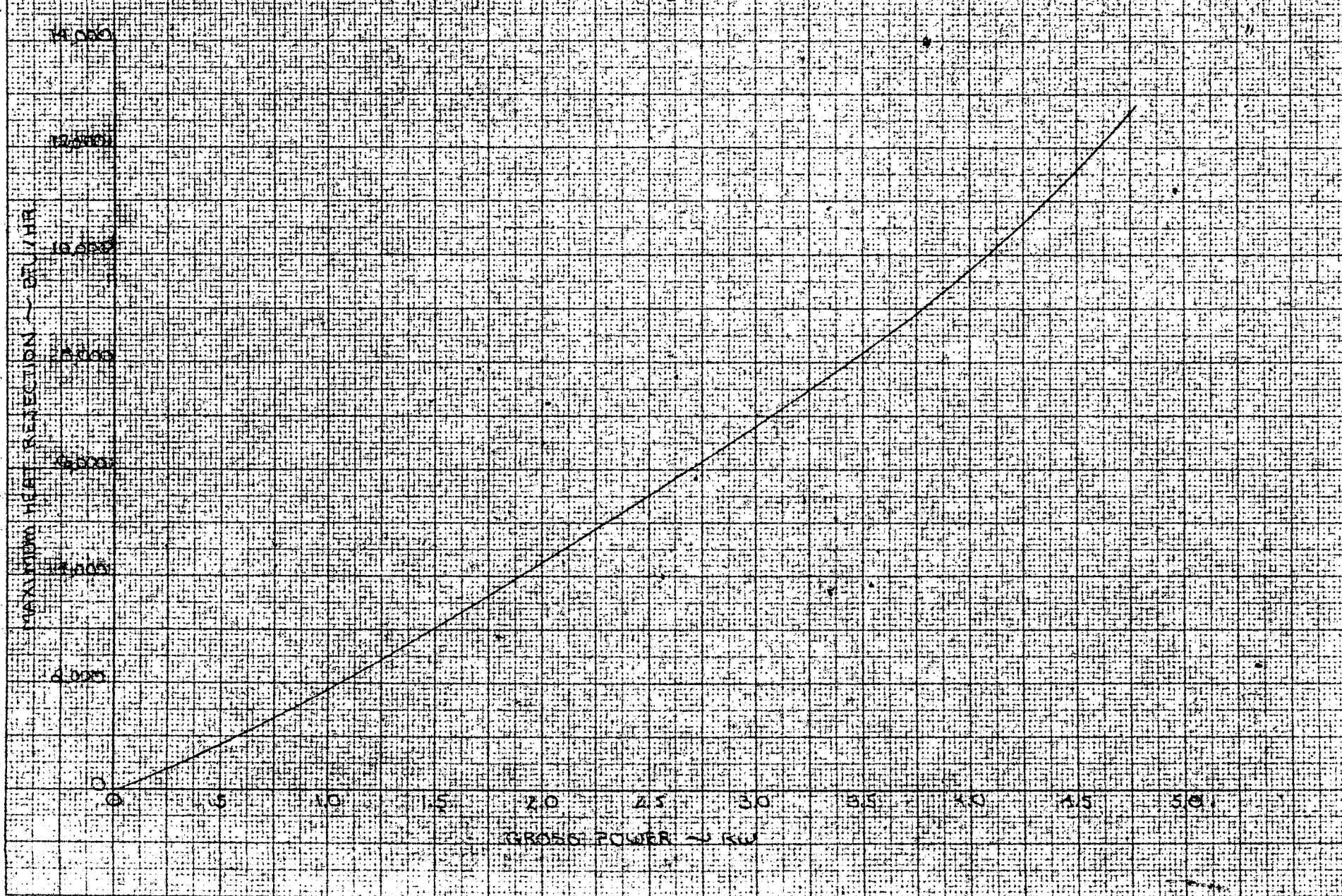
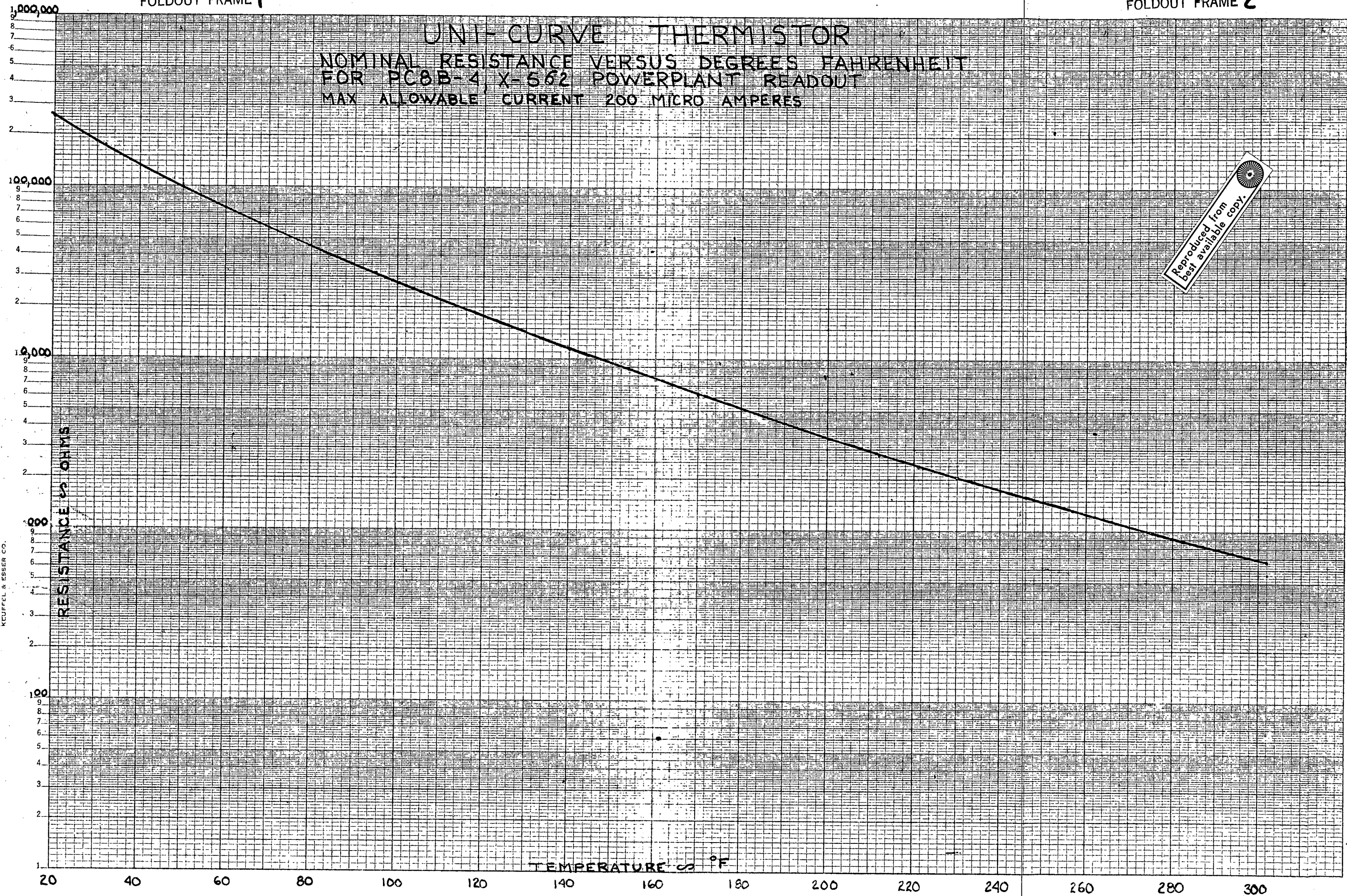


FIGURE XII



# UNI-CURVE THERMISTOR

NOMINAL RESISTANCE VERSUS DEGREES FAHRENHEIT  
 FOR PC8B-4 X-562 POWERPLANT READOUT  
 MAX ALLOWABLE CURRENT 200 MICRO AMPERES



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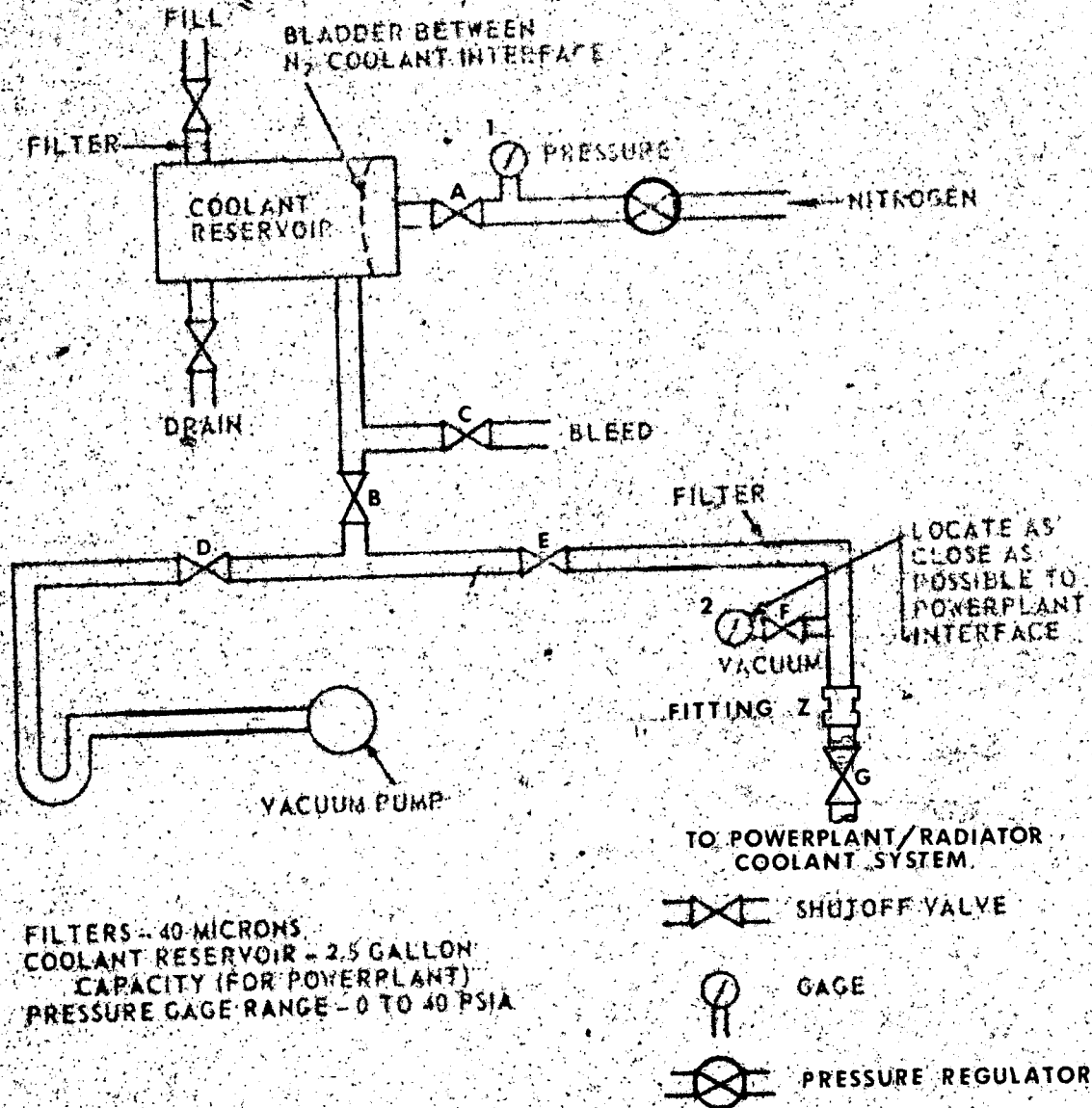


FIGURE XIV Schematic of a TYPICAL COOLANT FILL SYSTEM

PCD 40

WORK TO DIMENSIONS GIVEN—  
DO NOT SCALE

UNLESS OTHERWISE SPECIFIED

PCD 40

## CONNECTORS

J1: MS3106B22-8S

P1: MS3102A22-8P

J2: MS3106A16-11S

P2: MS3102A16-11P

J3: MS3112E14-12SX

P3: MS3116F14-12PX

J4: CANNON GK-12-31S

P4: CANNON GK-12-22C- $\frac{5}{8}$ 

J5: MS24266R-10-T-5S-9(100)

J6: MS24266R-10-T-5S-9(100)

J7: MS24266R-10-T-5S-8(100)

J8: MS24266R-10-T-5S-7(100)

J9: MS24266R-10-T-5S-N(100)

J10: MS24266R-10-T-5S-6(100)

J11: MS24266R-10-T-5S-N(100)

J12: MS3102A18-6S

P12: MS3106A18-6P

J13: MS3102A32-5S

P13: MS3106E32-5P

J14: BENDIX PTO05E-24-6IS (SR)

P14: BENDIX PTO66E-24-6IP (SR)

J15: MS3102A18-1S

P15: MS3106A18-1P

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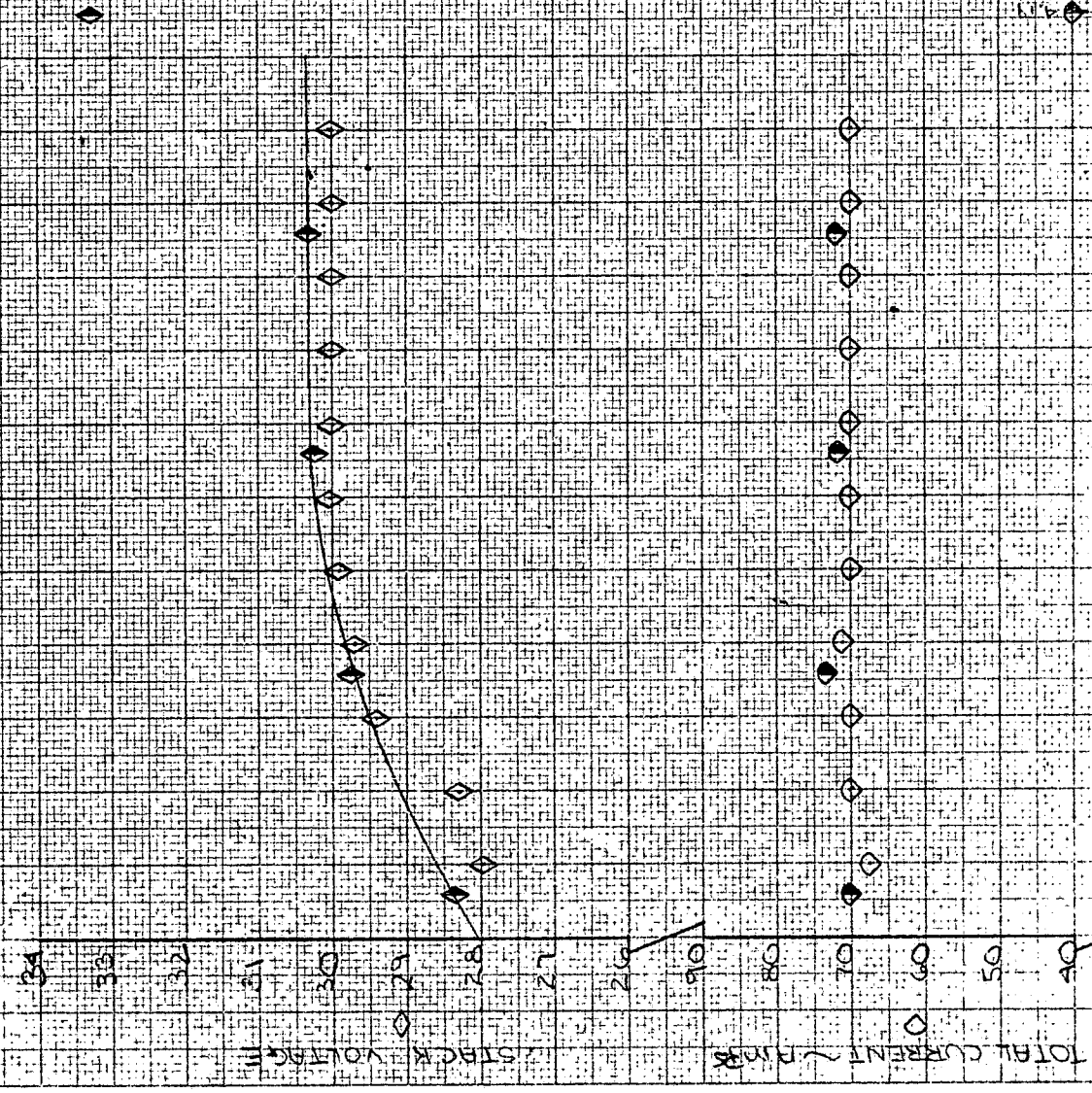
NAME A. TOWNSHAW	APPROVED	TITLE X-562	
DATE 4-70	SWEF	ELECTRICAL CONNECTORS	
PRATT & WHITNEY AIRCRAFT		MATERIAL / SPEC.	SKETCH NO.
DIVISION OF UNITED AIRCRAFT CORP.			PCD 40
EAST HARTFORD, CONN.		SHEET NO.	NO. OF SHEETS

FIGURE XV



X-502-1 BOOTSTRAP START  
ACCEPTANCE TEST

OPEN SYMBOLS ARE POWERPLANT INSTRUMENTATION  
HALF SHADED SYMBOLS ARE ADR INSTRUMENTATION



- COOLANT STACK INLET
- COOLANT STACK EXIT
- ◇ HYDROGEN CONDENSER EXIT
- △ TOP HEATER PLATE
- ▽ BOTTOM HEATER PLATE

